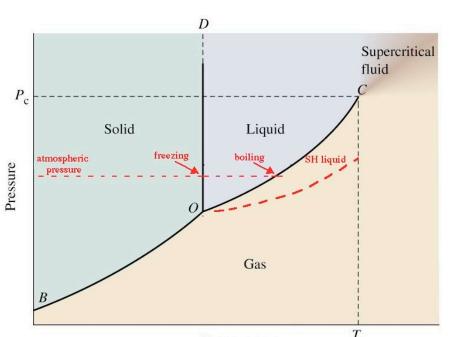
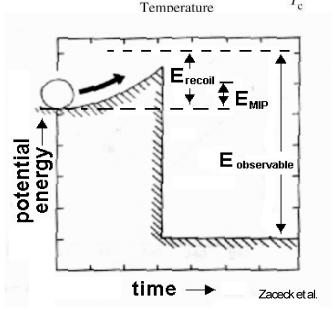


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- <10<sup>-10</sup> rejection factor for MIPs. INTRINSIC (no data cuts)
- Scalability: large masses easily monitored (built-in "amplification"). Choice of three triggers: pressure, acoustic, motion (video))
- Revisit an old detector technology with improvements leading to extended (unlimited?) stability (ultra-clean BC)
- Excellent sensitivity to both SD and SI couplings (CF<sub>3</sub>I)
- Target fluid can be replaced (e.g.,  $C_3F_{8,}$   $C_4F_{10,}$   $CF_3Br$ ). Useful for separation between n- and WIMP-recoils and pinpointing WIMP in SUSY parameter space.
- High spatial granularity = additional n rejection mechanism
- Low cost, room temperature operation, safe chemistry (fireextinguishing industrial refrigerants), moderate pressures (<200 psig)
- Single concentration: reducing or rejecting  $\alpha$ -emitters in fluids to levels already achieved elsewhere (~10-17) will lead to complete probing of SUSY models

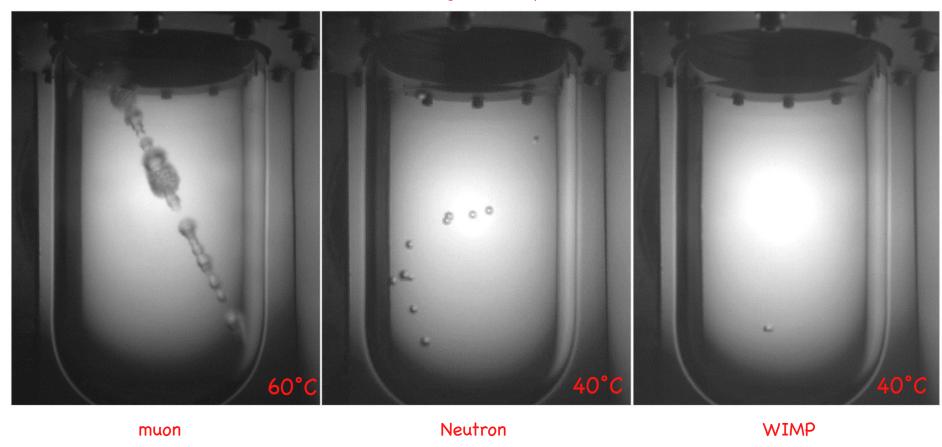




# Not your daddy's bubble chamber:

Conventional BC operation (high superheat, MIP sensitive)

Low degree of superheat, sensitive to nuclear recoils only



ultra-clean BC: Bolte et al., NIM A577 (2007) 569

- Detection of single bubbles induced by high-dE/dx nuclear recoils in heavy liquid bubble chambers
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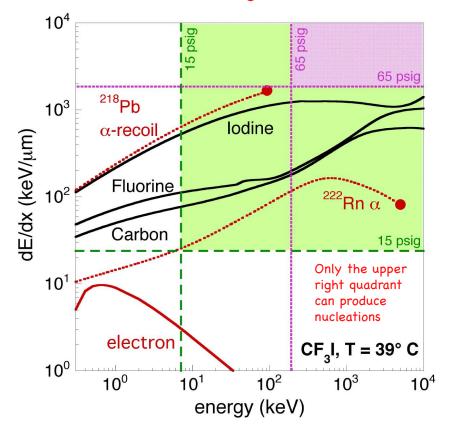
Seitz model of bubble nucleation (classical BC theory):

Threshold in deposited energy

$$E > E_c = 4\pi r_c^2 \left( \gamma - T \frac{\partial \gamma}{\partial T} \right) + \frac{4}{3} \pi r_c^3 \rho_v \frac{h_{fg}}{M} + \frac{4}{3} \pi r_c^3 P , \quad r_c = 2\gamma / \Delta P$$

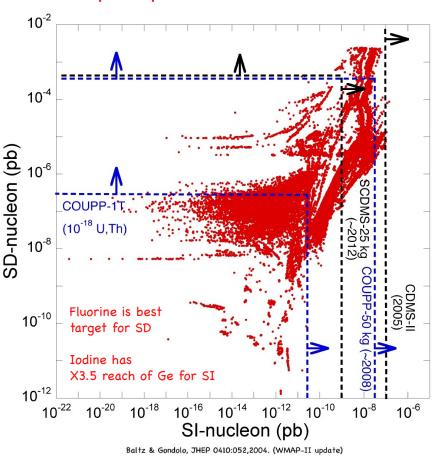
 $dE/dx > E_c/(ar_c)$ 

Threshold also in stopping power, allows for efficient INTRINSIC MIP background rejection



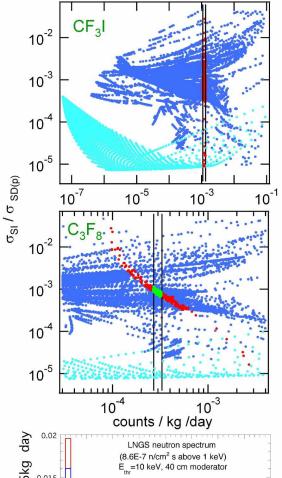
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#### An old precept: attack on both fronts



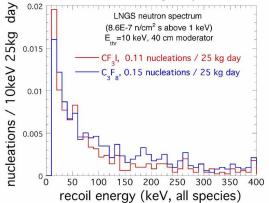
SD SUSY space harder to get to, but predictions are more robust and phase-space more compact. Worth the effort. (astro-ph/0001511, 0509269, and refs. therein)

- Detection of single bubbles induced by high-dE/dx nuclear recoils in heavy liquid bubble chambers
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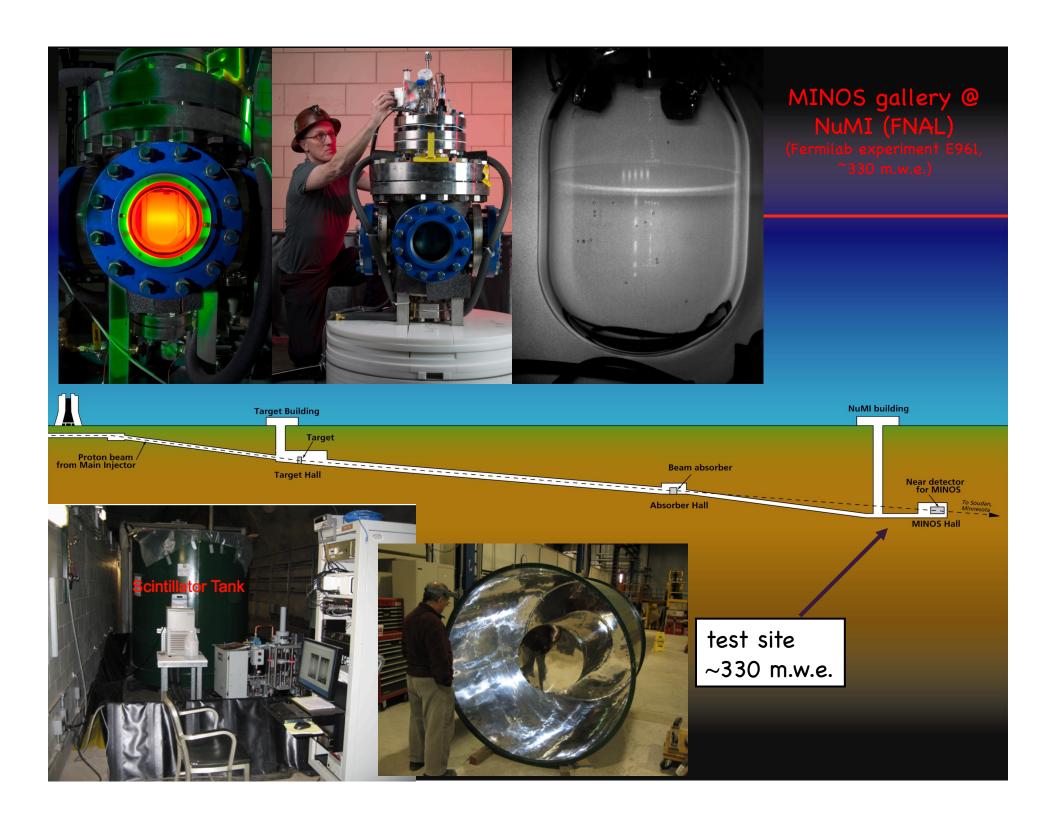


Bertone, Cerdeno, Collar and Odom (Phys. Rev. Lett. 99(2007)151301)

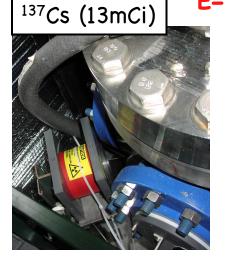
Rate measured in CF<sub>3</sub>I and C<sub>3</sub>F<sub>8</sub> (vertical bands) tightly constrains responsible SUSY parameter space and type of WIMP (LSP vs LKKP)

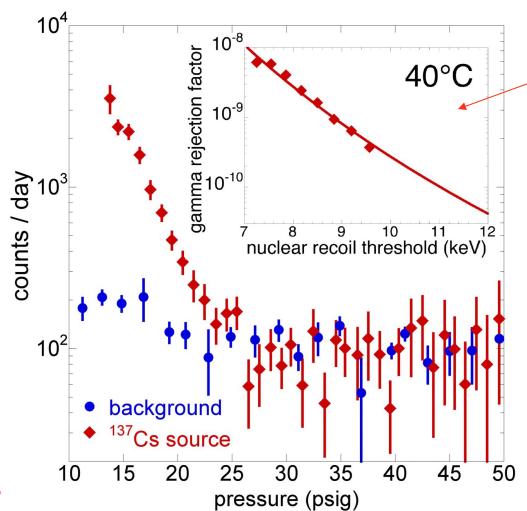


Neutrons on the other hand produce essentially the same rates in both  $(\sigma_n \text{ for F and I} \text{ are very similar})$ 



E-961 progress: let us start with the mistakes

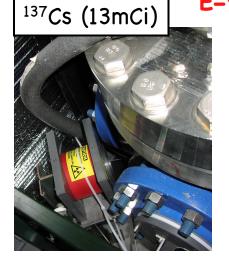


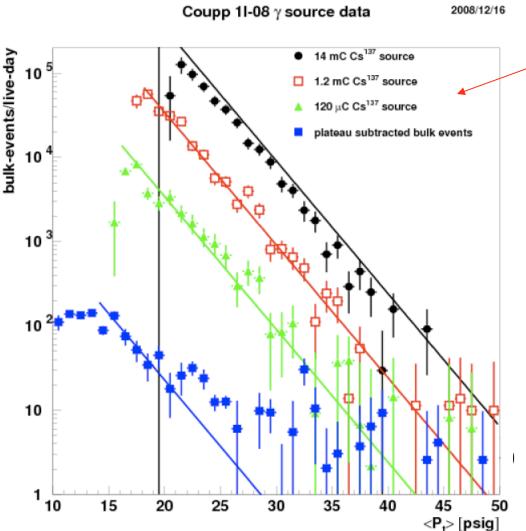


Best MIP rejection factor measured anywhere (<10<sup>-10</sup> INTRINSIC, no data cuts)

Other experiments as a reference: XENON ~10<sup>-2</sup> CDMS 10<sup>-4</sup>-10<sup>-5</sup> WARP ~10<sup>-7</sup>-10<sup>-8</sup> 14C betas not an issue for COUPP (typical O(100)/kg-day)
 No need for high-Z shield nor attention to chamber material selection

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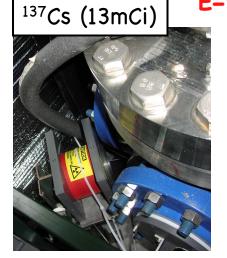


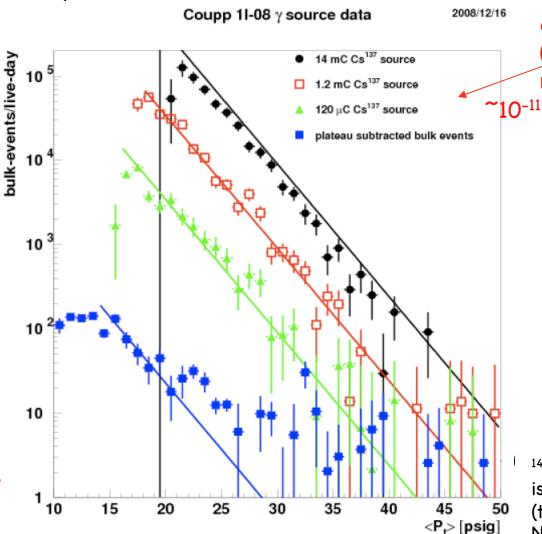


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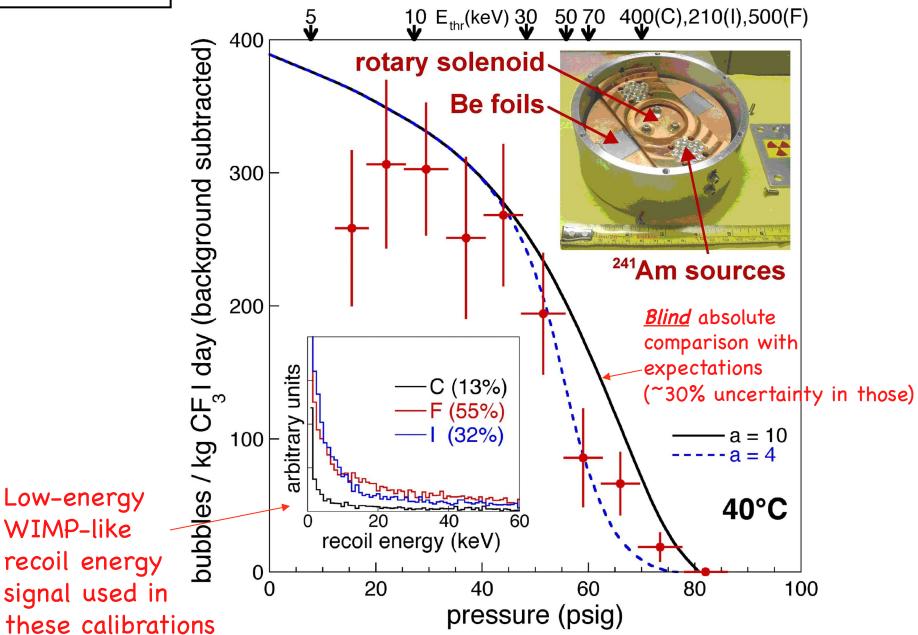


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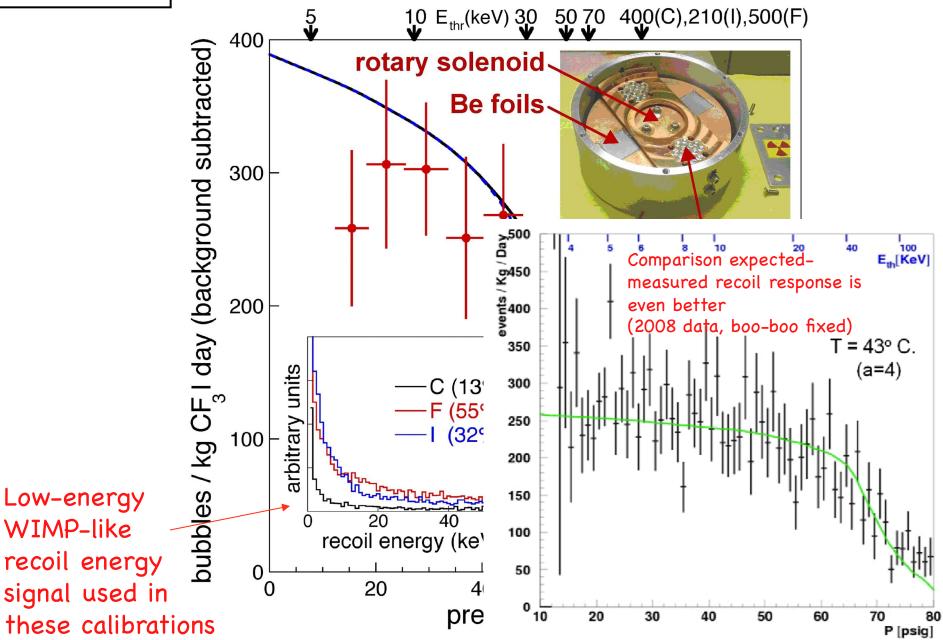
Switchable Am/Be (5 n/s)

# E-961 progress: let us start with the mistakes

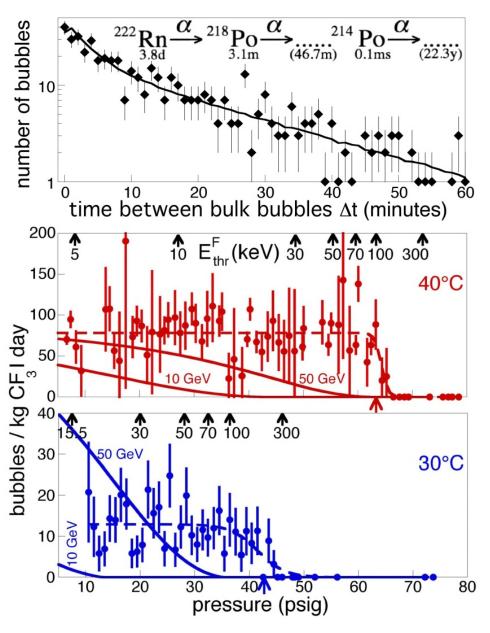


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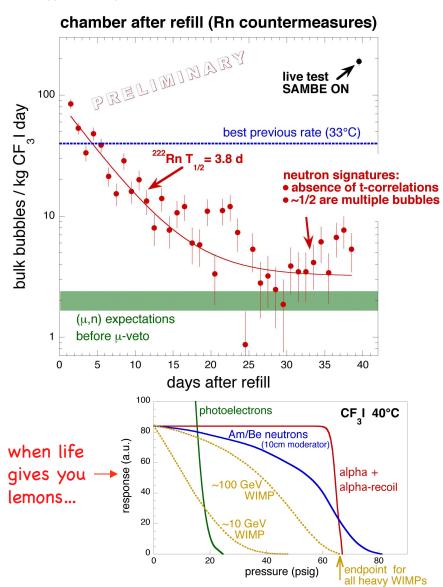
# E-961 progress: let us start with the mistakes



# E-961 progress: Rn control

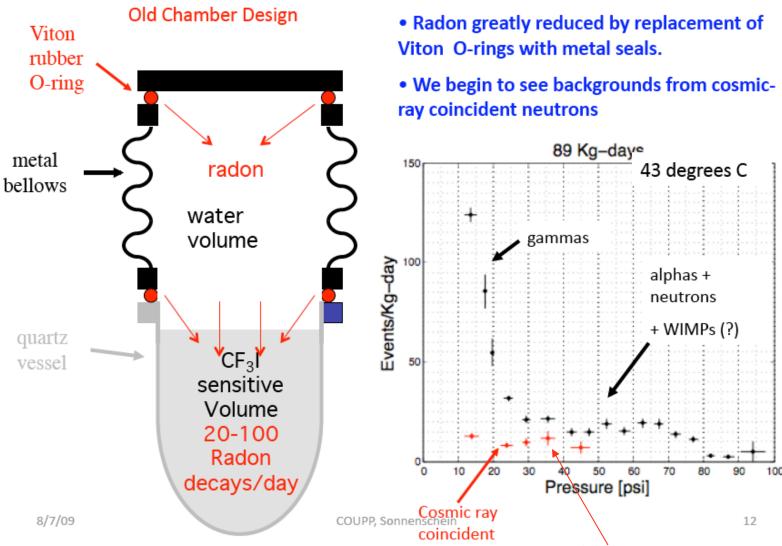


Our 1<sup>st</sup> results (Science 2008) came from a chock-full-o-radon: now mitigated by use of metallic seals.



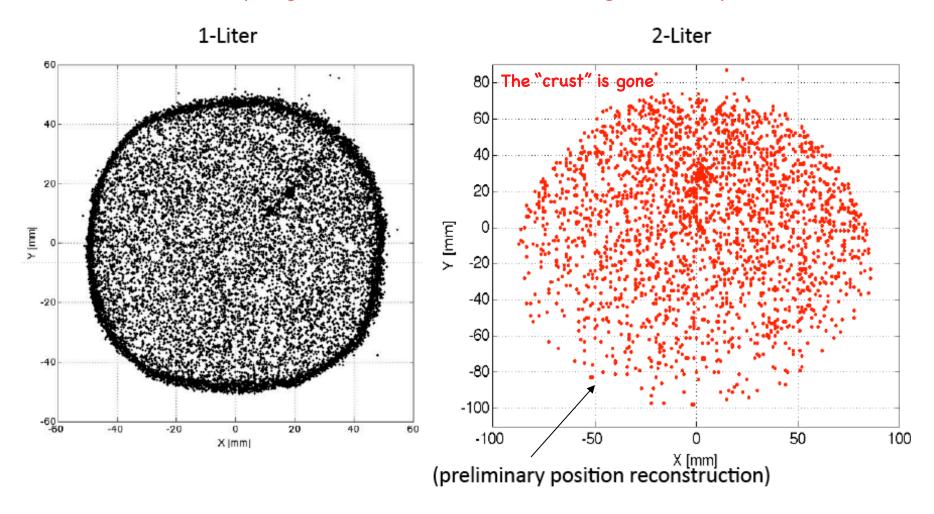
# E-961 progress: Rn control

# 2-kg Chamber 2008 Data



Make no mistake when we tell you about a ~1 c/kg-day goal at NUMI...

# E-961 progress: wall events a thing of the past

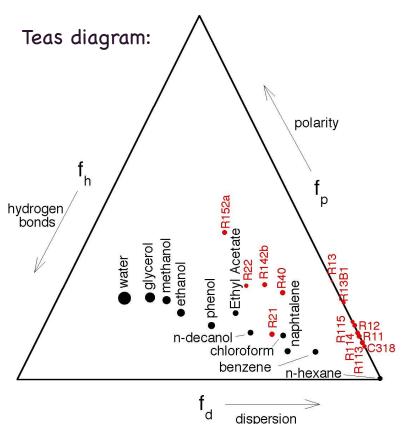


- We detected a ~50 ppb U,Th contamination in regular quartz used in early chambers.
- Alpha emission from surface was independently confirmed, at the same rate as wall evts.
- New chambers now featuring synthetic silica (~3 orders of magnitude lower U,Th content)
- New rate will allow us to reach 1 ton without any live-time penalty.
- Synthetic silica vessels available up to 250kg CF3I: extrapolation to ~500kg part of our DUSEL S4 charge.

# E-961 progress: fluid purification & handling

### "like dissolves like"

U & Th salts readily dissolve in  $H_2O$ , refrigerants do not. Solubility of U,Th in  $CF_3I$  expected to be very small (a situation similar to mineral oil-based v dets.)



 $\begin{array}{c} \text{Fractional cohesion parameters} \\ \text{for refrigerants and common solvants} \\ \text{(size of marker} \sim \delta_{\text{t}}) \end{array}$ 

component



First serious attempt at fluid handling/purification, to be commissioned during NUMI 60-kg fill.

So far we have only profited from SNOlab water availability (to reach already <5  $\alpha$ -like ev/kg-day)

We foresee most future effort on H<sub>2</sub>O purification.

# E-961 progress: alpha - nuclear recoil discrimination

#### Glaser (1955)

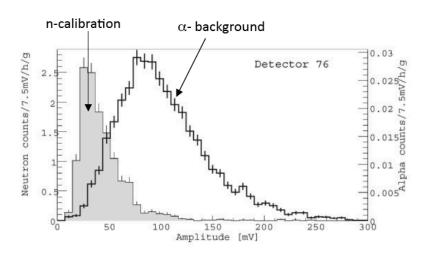
In order to see events more interesting than muons passing straight through the chamber, we took advantage of the violence of the eruption which produces an audible "plink" at each event. A General Electric variable-reluctance phonograph pickup was mounted with its stylus pressing against the wall of the chamber. Vibration signals occurring during the quiescent period after the expansion were allowed to trigger the lights and take pictures. In this way we saw tracks of particles passing through the chamber in various directions,

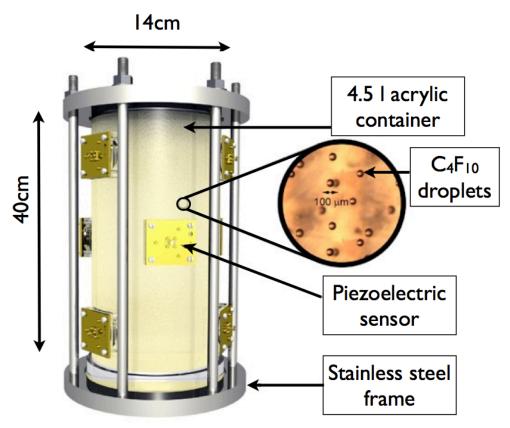
#### Martynyuk & Smirnova (1991)

The initial pressure in the volume V depends on the energy transmitted by the particle to that volume. Consequently, the characteristics of the acoustic pulse depend on the parameters of the particle responsible for formation of the bubble....

The parameters of these pulses must depend strongly on the characteristics of the particle.

#### PICASSO collab. (2009)





PICASSO demonstrates  $\alpha$  - nuc. recoil acoustic discrimination in Superheated Droplet Detectors (SDDs) F. Aubin *et al.*, New J. Phys 10 (2008) 103017

# E-961 progress: alpha - nuclear recoil discrimination

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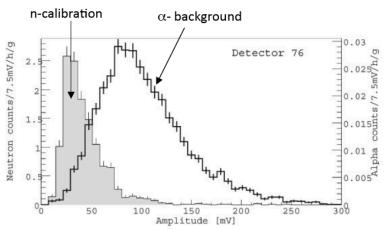
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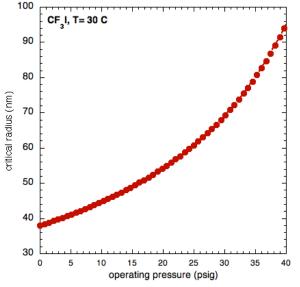
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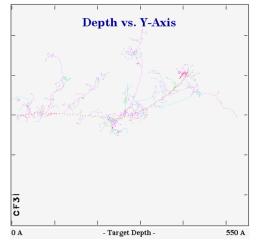




10 keV iodine recoil spans ~50 nm = ~1 critical radius (can create only ~one protobubble)

Alpha particles can create several along their much longer paths (one quaranteed, the  $\alpha$ -recoil).

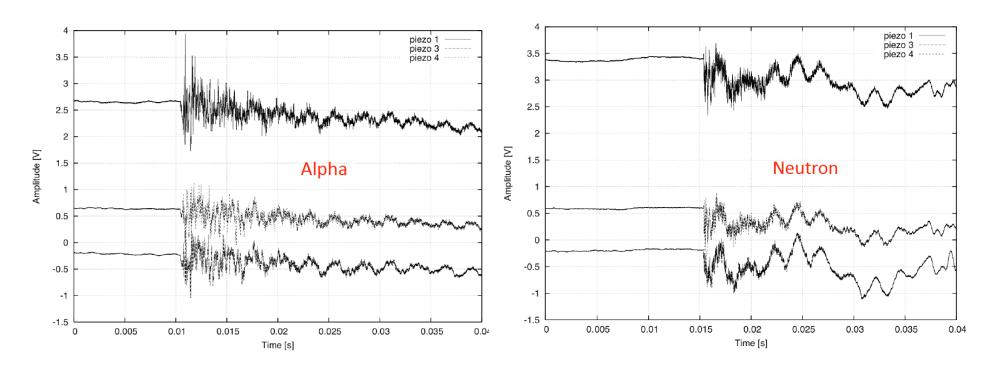




As exciting as the SDD PICASSO results are, we expect the effect to be much more dramatic in a BC...

- no alpha energy loss in gel, nor partial trajectory through droplet
- SDDs are an acoustically dispersive medium
- BC transparency allows for spatial corrections
- effect expected to be larger at freq. beyond Picasso piezo bandwidth.

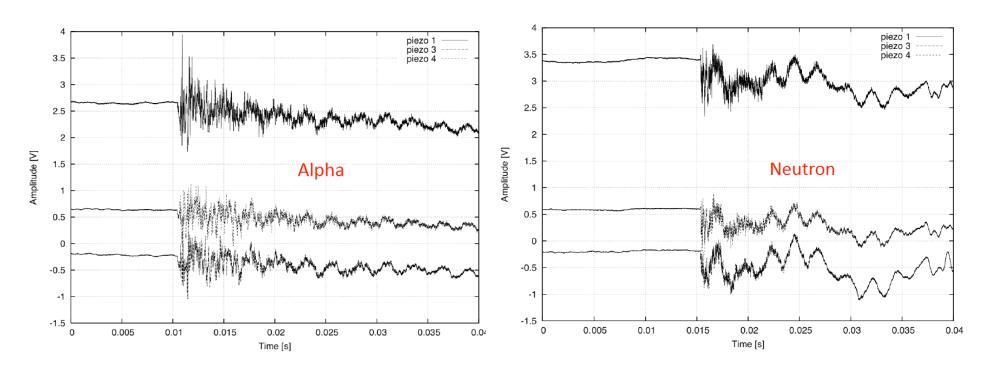
# E-961 progress: acoustic alpha - nuclear recoil discrimination



We observe two distinct families of single bubble bulk events in a 4 kg chamber:

- Discrimination increases with frequency, as expected.
- We have a handle on which is which (Rn time-correlated pairs following injection, S-AmBe calibrations, NUMI-beam events).
- ullet Polishing off the method, but potential for high discrimination against lpha's is clear.
- Challenge in obtaining same discrimination in the 60kg device: increasing sensors to 24, also their bandwidth (IUSB group)

# E-961 progress: acoustic alpha - nuclear recoil discrimination



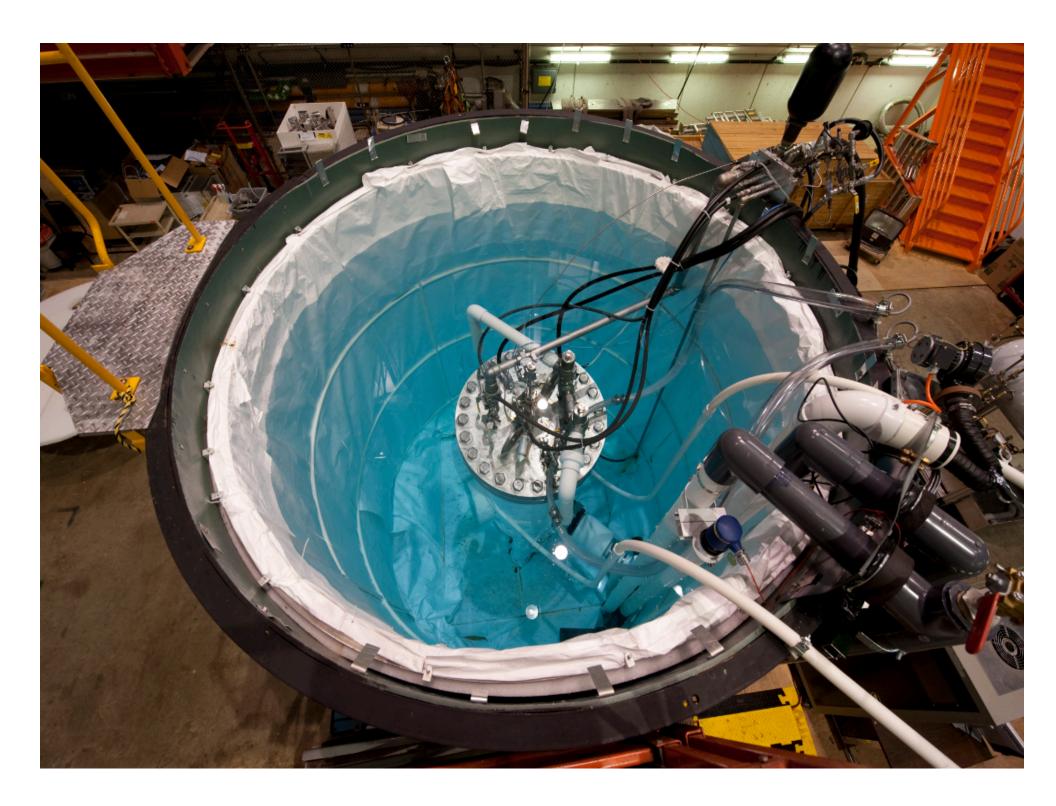
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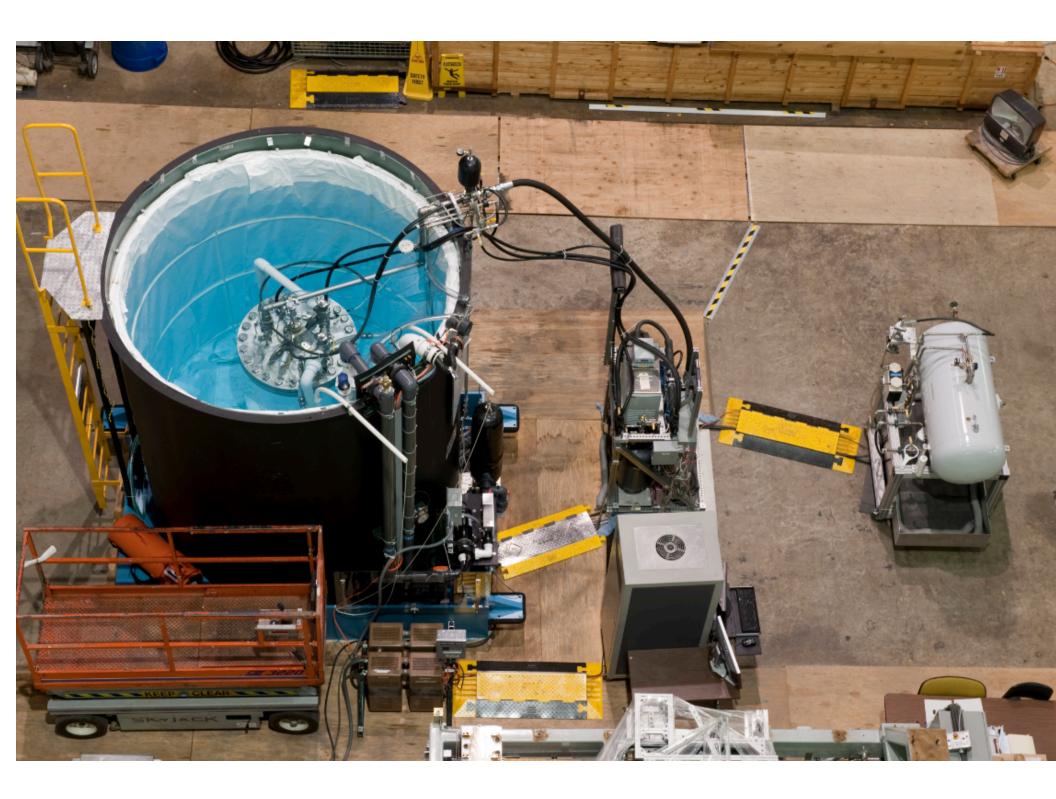
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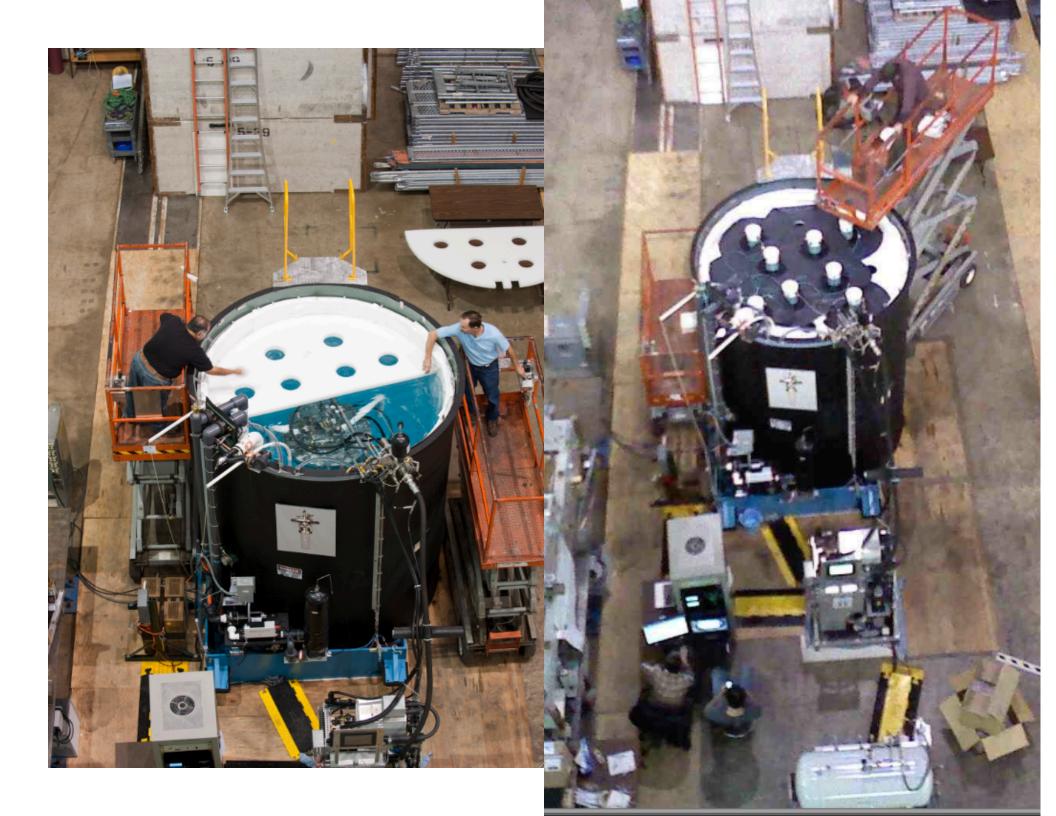
(sorry, we are presently rationing the eye-candy)





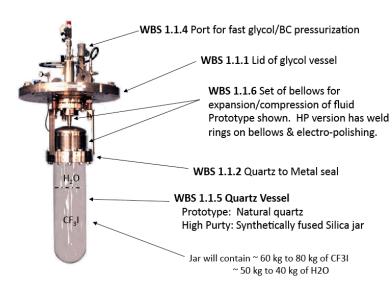


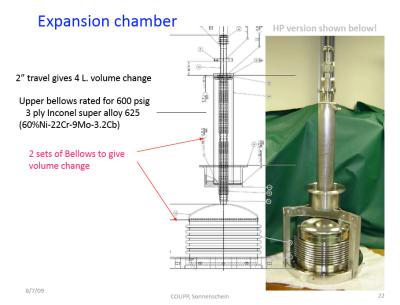




# E-961 progress: all sorts of progress

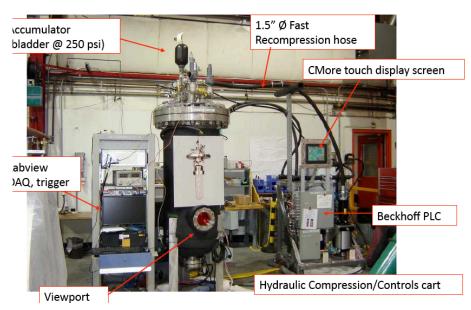
#### Inner Vessel Prototype Assembly for 60-kg Chamber





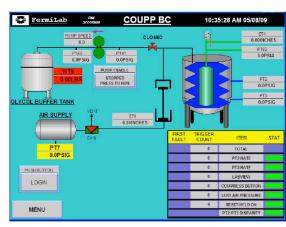
#### **Controls & Hydraulics**

Pictured below Peripheral Equipment for E-961 60 kg Engineering run



#### **Hydraulic Pressure Control System**

- Uses Programmable Logic Controller for high-reliability operation.
- About 20 instruments
- Touch screen control
- High speed pneumatic cylinder for fast compression
- Slow high-pressure pump controlled by PID loop for pressure stabilization as temperature changes.
- Successful system tests in 2008 engineering run.



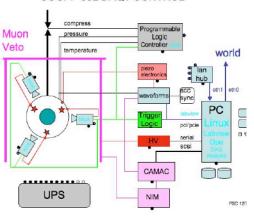
# E-961 progress: all sorts of progress

#### Video, Trigger, & DAQ

#### Photograph a well illuminated, sensitive, bubble chamber at ~100Hz with VGA resolution (480X640) BW cameras.

- Declare a trigger when an image changes.
- Combine & manage triggers from cameras, pressure controller, operator
- Record bit map images/camera + state and other data ~10Mb/trigger. Analyze events as taken for monitoring purposes.
- Provide a user interface for monitoring, control and DAQ
- Robust, stand alone, remote operations via the network.

#### COUPP 30L DAQ / CONTROL



DAQ Parameters
 Trigger rate 100-5000/day
 Trigger deadtime 30 seconds
 time resolution ~10 msec

#### Diffuser and LED grid fitted to inner assembly





#### Water Tank Veto/Shield

- Water tank has three functions:
  - Neutron shielding
  - Cerenkov muon detector
  - Heat bath for controlling the temperature chamber (40 degrees C
- Double walled 4000 gallon polyethylene tank with insulating foam in annular space and light-tight lid.
- 12 x 8 inch phototubes supported by a floating foam raft.
- An engineering note has been written outlining a design for a water tank that c be assembled from thin steel sheets, wh are narrow enough to fit down a mine shaft.



#### First cosmic ray observations in the water shield





8 Inch PMT



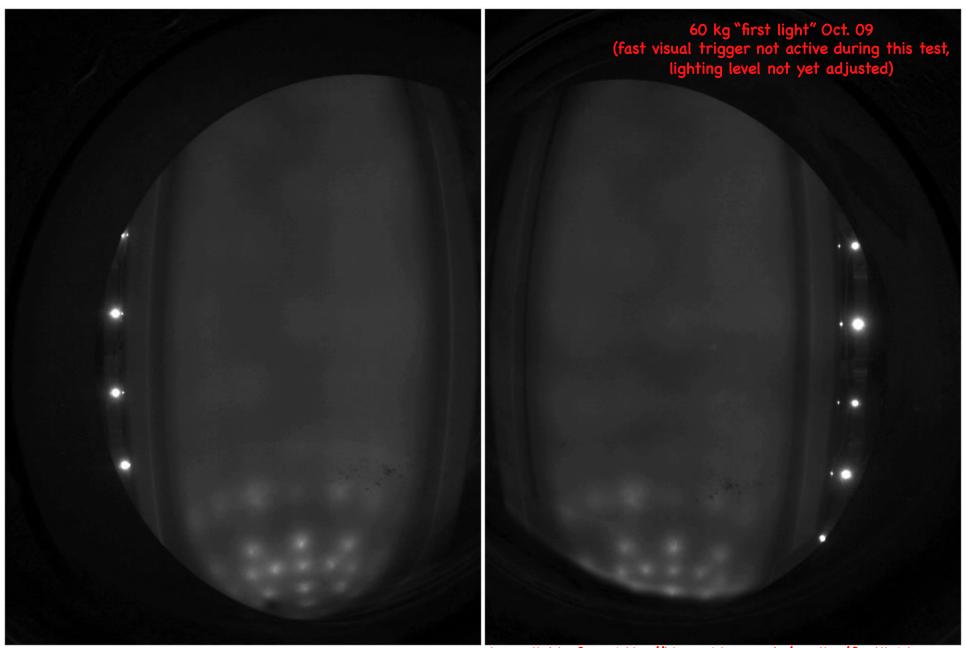
Pulses in the 3 PMT's, with a scintillator telescope trigger selecting for muons crossing the tank.

- Light yield of ~10 p.e. per tube, agrees with predictions.
- Efficiency measured to be >98%

8/7/09 COUPP, Sonnenschein

32

# E-961 progress: all sorts of progress



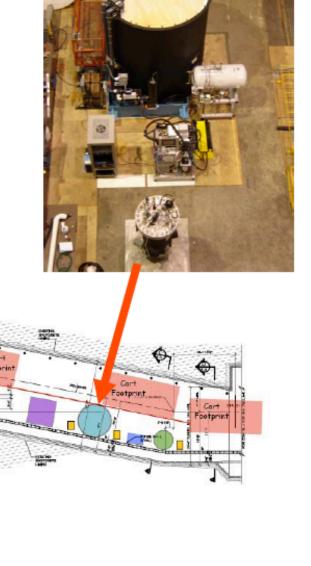
Movie available from http://kicp.uchicago.edu/~collar/firstlight.mov

# E-961 progress: all sorts of progress NuMI Tunnel Installation

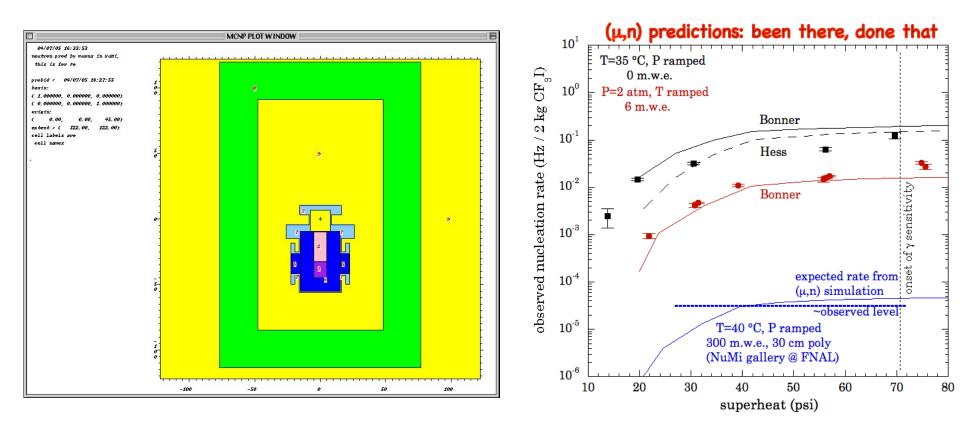
Relay Rock

COUPP, Sonnenschein

 We have arranged for space in the NuMI tunnel at Fermilab, at a depth of 300', for our initial run.



# P-999: When will we be ready for SNOlab?

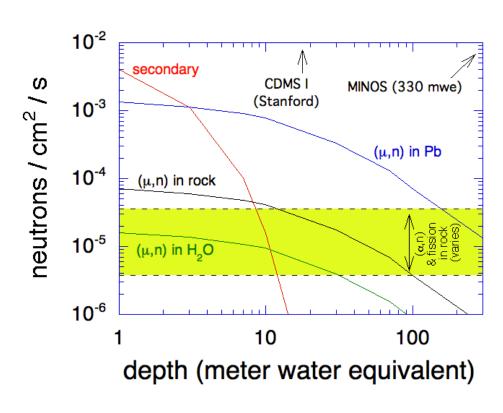


Technical criteria: >50% live time (check?), efficient triggering & DAQ, unattended operation, when SNOlab infrastructure ready for us (tank, crane, safety, utilities).

Most importantly, when we understand the backgrounds at NUMI:

- <u>Measurement/Simulation effort</u> underway to predict all neutron sources (environmental/cosmic muon induced/beam associated)
- Situation now "complicated" by desire to have best possible acoustic discrimination in the 60kg chamber. One wishes all complications in life were like this one.

# P-999: When will we be ready for SNOlab?



# SNO neutral current detector PSD (large 3He counter, in Bonner configs. in our case)

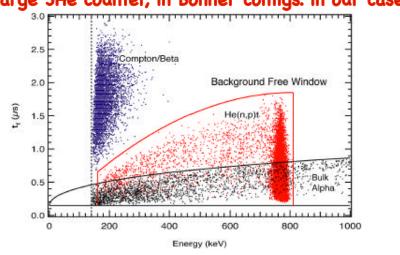


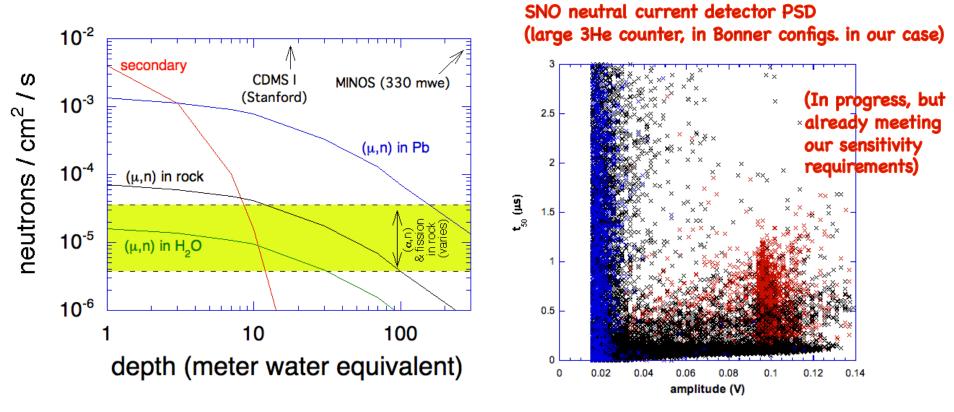
Figure 4.16: T vs. E plot of analyzed data demonstrating the "background free window" – a region of phase space occupied only by the <sup>3</sup>He(n,p)t events [51]. This region contains 45% of all neutron events, and is bounded by lower risetime (t,) bulk alpha activity, and higher risetime Compton events.

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### P-999:

# Summary of Proposal

- COUPP-60 detector expected be limited in sensitivity by shallow depth of NuMI site by late 2010.
- We propose to move the detector to Snolab after successful testing at NuMI.
- Snolab site was chosen over Soudan because of greater depth, better technical support and opportunities to expand collaboration.
- Snolab director (Nigel Smith) has agreed to provide manpower and equipment for the COUPP-60 installation provided that the equipment can be purchased before the end of 2010. He would like to see approval by Pier before purchasing, preferably before the end of November.

#### P-999:

# Cost Sharing With SNOLAB

Documented in letter from Snolab director, July 21, 2009.

#### SNOLAB would be responsible for

- Water shielding tank (86 k\$)
- Crane (31 k\$)
- Basic infrastructure and utilities (41 k\$)
- Misc. tools and furniture (13 k\$)
- Fire alarm (82 k\$)
- Labor to install this equipment and assist with detector installation (207 k\$)
- Engineering associated with these installations.
- Ongoing technical support for maintenance of experiment (1/4 FTE)
- Staff scientist

#### (total 460 k\$ CAD including 50% contingency)

Fermilab, U. Chicago and IUSB would be responsible for

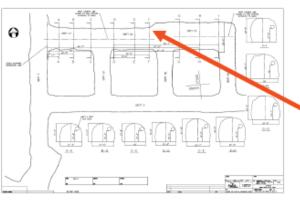
- The detector
- Shipping materials to SNOLAB
- Installation of the detector
- Operating the detector
- Non-routine maintenance.

### P-999:

# **SNOLAB Ladder Lab location**

- Consultations with SNOLAB engineering staff have resulted in a possible layout in one of the 'ladder lab' locations.
- Already meets cleanliness specs.
- Pure water is available for filling tank.
- Utilities have not been installed yet.
- No existing crane.
- Fire alarms needed.





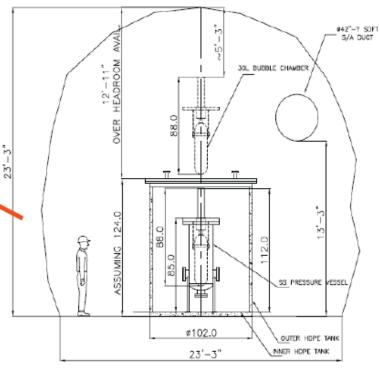
#### (parts being purchased this month)

MAY 6, 2009

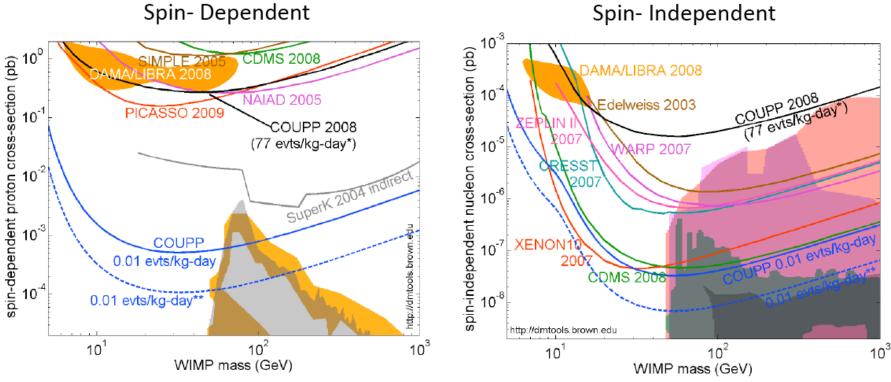
COUPP DETECTOR AT SNOLAB U/G LABORATORY
IN DRIFT C2 CROSS-SECTION F-F
DWG# SLDO-UGL-SK-0002-01

NOTE

1. OVERALL DETECTOR DIMESIONS ARE NOT WELL DEFINED



### P-999: Projected sensitivity



Some (intentionally) vague projections to guide your eye

Acoustic discrimination is a true — game-changer (now purification AND/OR rejection)

Once we succeed in achieving improved levels of radiopurity, we will quickly be limited in sensitivity by the shallow depth of the NuMI tunnel.

Rate [Events/kg-day]	
77	Published 2006 data
~10	COUPP-2 2007 run
1	Goal for NuMI Phase of COUPP-60; limited by untagged neutron backgrond in NuMI tunnel
~0.01	State of the art for alpha contamination of fluids established by Borexino, SNO.
<0.001	Neutron background at deep underground site

# Further in the future (not your charge, but worth mentioning)

- NSF DUSEL S4 funded (1.4 MUSD) for engineering studies of 500kg chamber (7,400 mwe DUSEL level). Systems extrapolation from 60 kg to 500 kg relatively straightforward, but issues remain:
- seamless synthetic silica vessels of the required size
- efficient acoustic discrimination  $(1/r^2...)$
- purification and fluid handling
- safety aspects (SNOlab deployment good training ground)
- PASAG report (few days ago):

In all budget scenarios, the Xenon100 upgrade, the LUX350 detector, an effort on DAr, funding for the MiniCLEAN detector, the additional towers in SuperCDMS Soudan, the COUPP 500 construction, the 100-kg SuperCDMS-SNOLAB experiment and the phase II upgrade to ADMX are supported.

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(Thanks Steve & co.)